Extending the Planting Period of Dormant and Growing Norway Spruce Container Seedlings to Early Summer

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In order to make mechanized planting economically viable, the present spring planting period for Norway spruce (*Picea abies* (L.) Karst.) seedlings in Scandinavia needs to be extended. To evaluate the possibilities to extend the planting period, six field experiments were established in four years during which frozen-stored, dormant seedlings and actively growing seedlings targeted for spring planting were planted regularly from mid-May to mid-July or the end of August. The survival of actively growing seedlings did not differ between planting dates from mid-May to mid-July. For dormant seedlings, however, the later in summer they were planted the lower was the survival. Oversized seedlings grown in the nursery in containers of too small volume, which were usually planted after mid-June, resulted in reduced growth of seedlings after planting. Root egress (growth of roots from root plugs into the surrounding soil) was most rapid in July and early August and slowest in May and September. Results showed that with dormant seedlings the planting period can be extended from May to mid-June without increasing mortality or reducing growth. The planting period for seedlings stored outdoors and those seedlings that were already growing in June for the purpose of spring plantings can be extended even longer, but it must be kept in mind that the risk of mechanical damage and reduced growth increase due to brittleness of the shoot and increased height. Further research is needed to evaluate the risks in practical scale plantings and with seedlings that are specially targeted for planting after mid-June.

Keywords carbohydrate, frozen storage, height growth, hot-lifting, Norway spruce, planting date, root growth, survival
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1 Introduction

In Scandinavia, the conventional planting period for Norway spruce (*Picea abies* (L.) Karst.) container seedlings, about 4 weeks in May, needs to be enlarged. During the last decade the number of seedlings planted by machine has increased (Vartiamäki 2003). To ensure that the investment in an expensive planting machine is economically viable, the operation time should be enlarged to a longer period than the conventional spring planting.

Planting of growing Norway spruce (Kinnunen 1989) and Scots pine (*Pinus sylvestris* L.) (Kinnunen et al. 1974, Valtanen et al. 1986) paperpot seedlings in early summer has previously been studied in Finland, with promising results. In British Columbia, Revel et al. (1990) showed that planting date had little effect on survival and growth after planting of freshly-lifted, growing white spruce (*Picea glauca* (Moench) Voss) bare-root seedlings planted in June. Their results indicated that extension of the planting period is possible. However, due to changes in container types and in growing and planting methods, it is necessary to ensure that, by using the present types of container seedlings the field survival of Norway spruce seedlings planted in early summer would not decrease from that obtained in conventional spring planting.

Regardless of planting date, frozen-stored seedlings are dormant at the time of planting. The period between planting date and first autumn frost should remain long enough to ensure time for full development of the new shoot and bud and for hardening of seedlings. For Central Finland provenances of Norway spruce seedlings, the growing period in the second growing season lasts about 700 degree days (d.d.) (Koski and Sievänen 1985). In addition, frost hardening of seedlings starts at cessation of height growth, and growing seedlings tolerate only about –3 to –4 °C (Glerum 1973). Planting of dormant seedlings later in the growing season also means extended frozen storage, during which carbohydrate reserves can decrease and seedlings may dry out due to respiration (Ritchie 1982, Jiang et al. 1994). These changes may decrease both the root growth potential (Ritchie 1982) and the stress resistance of planted seedlings (Jiang et al. 1995).

Root growth of seedlings varies during the growing season. According to Kaakinen et al. (2004), growth of the current-year root of Norway spruce seedlings is slow until height growth ceases. In their study, seedlings grown hydroponically in a growth chamber increased allocation to roots, which started to grow more in mid-July. Helenius et al. (2005), on the other hand, showed that, when the seedlings are planted in mid-June into moist soil, growing Norway spruce seedlings have greater root egress than frozen-stored dormant seedlings. Root growth, nutrient and water uptake of roots is dependent on soil temperature. Low root-zone temperatures (RZT) reduce the uptake of water (Lopushinsky and Kaufmann 1984) and nutrients by roots (Bowen 1970), decrease the growth of roots (Vapaavuori et al. 1992) and of the whole seedling (Lyr 1996). According to Vapaavuori et al. (1992), for Scots pine and Norway spruce seedlings the threshold RZT for root initiation is between 8 and 12 °C. In the study of Iivonen et al. (1999), the threshold RZT for root growth and metabolism of Scots pine seedlings was 13 °C. In any case, in May the RZT in Central Finland is lower than those thresholds, not increasing above them until June and July (Luoranen et al. 2003). Thus, field performance of seedlings planted after the conventional planting period may even be improved due to the increased potential for root egress in warmer RZT.

The aim of this study was to investigate possibilities to extend the planting period of Norway spruce from spring to early summer by planting either (i) actively growing or (ii) dormant container seedlings targeted for spring planting. We hypothesized that, without risk of reduced survival and growth, it is possible to plant both actively growing and dormant seedlings in early summer. Furthermore, we supposed that compared to planting in May, the risk of dormant planted seedlings to die increases later in summer. When later planting means also the longer winter storage, the effects of the storage duration on root egress and carbohydrate concentrations in needles were also studied.

2 Material and Methods

2.1 General Description of Experiments

Seedlings for experiments were grown at the nursery of Suonenjoki Research Unit. Experiments were established on a former nursery field and two forest sites (Table 1) in Central Finland (latitude of 62°, longitude of 27° and altitudes between 90 and 130 m asl) over a period of four years. Experiments in which only actively growing seedlings were planted are called GRO, and those in which frozen-stored and still dormant seedlings were planted are called DOR; if both growing and dormant seedlings were planted, the name of the experiment was GRODOR. The year of establishment is used for assigning experiments. Plantek 81F trays (81 cavities per tray, 85 cm^3 per cavity, 546 cavities per m^2, Lännen Plant Systems, Finland) were filled with base-fertilized sphagnum peat. In experiments GRO98, GRO99, GRO00/A and GRO00/B, seedlings over-wintered outdoors. Until each planting date, seedlings were irrigated and fertilized according to the normal commercial culturing practices at the Suonenjoki Research Nursery. In early May 1999 there were severe night frosts (during several nights, of which one the minimum temperature at ground level was –10.6 °C) which damaged part of the terminal buds of seedlings in GRO99. Although the aim was to plant only healthy seedlings, unburst damaged buds were difficult to recognize, and some damaged seedlings were planted in some earliest dates. No insecticides against pine weevil were used.

For GRODOR00 (9 boxes, 80 seedlings in each) and DOR01 (5 boxes, 150 seedlings in each) seedlings were packed in cardboard boxes on 22 October 1999 and 26 October 2000, respectively, and stored frozen at –3 °C. Before planting, the boxes were moved to the growth chamber (+8 °C) for 4 days, then opened and moved outdoors into the shade (89% of the natural photosynthetically active radiation (PAR) was intercepted, daily mean temperature from 3 °C to 23 °C depending on date) for 2 days. In DOR01, part of the seedlings stored frozen for 28, 32 and 36 weeks had aphids and grayish fungal mycelia on their needles. In both GRODOR00 and DOR01 experiments (only in root egress test), seedlings in the growing phase were also included. They were

Table 1. Site and seedling information for experiments established in years 1998, 1999, 2000 and 2001. The phase of the seedlings indicates the growing phase of Norway spruce container seedlings at the time of planting. Dormant seedlings (D) were stored frozen, and their terminal buds were dormant. Growing seedlings (G) over-wintered outdoors; and excluding the first planting dates in May, the terminal buds had swollen, burst or flushed. Stoniness of forest sites are: 0 = no stones, 1 = few stones, 2 = normal stoniness, 3 = stony. Methods for mechanical soil preparation and weed control are: H = harrow and tilling, DT = disc trenching, M = ditching and mounding, W = mechanical weed control in later years.

Experiment	GRO98	GRO99	GRO00/A	GRO00/B	GRODOR00	DOR01
Site location	Suonenjoki	Pieksänmaa	Suonenjoki	Suonenjoki	Suonenjoki	Suonenjoki
Soil type	Sandy field	Coarse sand	Coarse sand [a)]	Coarse sand	Sandy field	Sandy field
Stoniness	0	2	2	1	0	0
% of organic matter	4.6	5.6	3.1	2.7	5.5	5.5
Particles < 0.06 mm, % in 0-20 cm depth	6.5	4.0	3.3	3.0	5.4	5.4
Scarification and weed control	H, W	DT, W on Aug. 2000	DT	M	H, W	H, W
Sowing date	29 Apr 1997	12 Jun 1998	29 Apr 1999	29 Apr 1999	29 Apr 1999	28 Apr 2000
Planting dates	18 May –6 Jul	19 May –14 Jul	24 May –19 Jul	24 May –19 Jul	17 May –23 Aug	30 May –25 Jul
Planting year	1998	1999	2000	2000	2000	2001
Planting interval	Weekly	Weekly	Biweekly	Biweekly	Biweekly	Biweekly
Phase of seedlings	G	G	G	G	D and G	D

[a)] < 50 cm depth in the ground soil contains small (< 0.06 mm) particles 10%.

over-wintered outdoors in trays and raised according to commercial production practices at Suonenjoki Research Nursery until planting.

In all experiments established in 2000, seedlings were from the same batch. At the time of planting, those seedlings had succulent new shoots which were sensitive to mechanical damage and breakage on 5 July in GRO00/A and B and on 12 July in GRODOR00. In GRO98, GRO99, GRO00A and B and DOR01, on each planting date 20 seedlings were planted in six blocks and in GRODOR00 16 growing and 16 dormant seedlings in five blocks (Table 1). GRO98 and GRODOR00 were established on the former nursery field and seedlings were planted in rows [0.5 m between seedlings in a row and 0.8 m between rows]. DOR01 was also established on the same field, but the seedling distance in the rows was 0.35 m (only dormant seedlings were planted on the field). In the disc-trenched forest sites (GRO99 and GRO00/A), each plot was 7 m × 7 m; and seedlings were planted about 0.5 m apart. On the ditched and mounded forest site (GRO00/B), one seedling was planted into each mound. In GRO00/A and GRO00/B, seedlings in both parts (mounded and disc trenched) were planted on the same days.

2.2 Measurements

The height of the seedlings was measured to an accuracy of 0.5 cm from ground level to the top of the seedling at the time of planting and in the end of each growing season. Each autumn, the vigour of the seedlings was scored as 1) dead, 2) severely damaged, 3) weakened or 4) healthy. For statistical analysis, categories 3 and 4 were combined. For binary logit analysis, categories 1 and 2 were reclassified as damaged (1) and classes 3 and 4 as healthy (0).

2.3 Root Egress Tests

In GRO99 and DOR01, 20 randomly selected seedlings from each planting date were planted into the sand-filled plastic pots (0.75 l) on each planting date (in DOR01 continued until 19 August). Seedlings were grown for three weeks under natural photoperiod and light conditions without additional heating. They were irrigated with tap water at least twice a week. In GRO99, on some planting dates spring frost damaged the terminal buds (Table 2). In DOR01, on some planting dates aphids were observed on the needles of frozen-stored seedlings (Table 2); and on 13 June, 20% of the seedlings had signs of gray mould or looked dry and weakened at the time of planting. In actively growing seedlings, on some of the planting dates, the terminal buds were damaged, and the seedlings grew in height from other buds (Table 2). After planting on 11 and 25 July, the seedlings were sprayed with synthetic pyretroids. After they were grown for three weeks, sand was cleaned from the root plug; and roots grown out from the peat plug, referred to later as new roots, were cut, washed, dried in an oven for 24 h at 105 °C and weighed (± 1 mg).

2.4 Carbohydrate Concentration of Needles

In DOR01, three pooled needle samples (47 needles from 3 seedlings in each) were collected for carbohydrate analysis: first, prior to planting (on 16 May 2001, storage duration 28 weeks) when

Table 2. Percentage of growing seedlings with bud damage caused by spring frost in the nursery and frozen-stored, dormant seedlings on which aphids were observed on needles during the root egress test.

Experiment	Phase		19 May	26 May	1 June	10 June	16 June	23 June	1 July	7 July	14 July
GRO99	Growing	Bud damage:	15	35	10	25	20	0	0	0	0
			22 May	30 May	13 June	27 June	11 July	25 July			
GRODOR00	Dormant	Aphids:	0	50	0	60	5	35			
GRODOR00	Growing	Bud damage:	0	35	0	15	10	25			

Table 3. Monthly mean temperatures (°C), precipitations (mm), temperature sums, date of the first autumn frosts and the 30-year average at Suonenjoki Research Station during the 1998 to 2003 growing seasons.

Temperature, °C	1998	1999	2000	2001	2002	2003	1974–2003
May	8.2	6.4	9.2	7.6	10.8	10.1	9.0
June	13.8	18.4	14.1	14.2	15.7	12.0	14.2
July	16.2	17.3	16.6	18.7	18.3	19.9	16.5
August	12.9	13.4	13.9	14.6	17.1	14.3	14.2
September	10.0	10.6	8.2	10.4	8.7	10.0	9.1
Temperature sum, d.d.	1161	1391	1265	1346	1458	1301	1220
Date of the first autumn frost	27 Sep	17 Oct	7 Sep	25 Sep	20 Sep	3 Sep	
Precipitation, mm							
May	22.4	27.6	38.6	55.3	31.8	56.3	37.5
June	54.0	48.9	64.5	61.3	104.6	72.4	67.6
July	143.2	92.3	84.6	81.4	73.4	67.8	83.8
August	96.2	25.1	81.2	80.4	47.8	81.0	80.3
September	17.7	37.5	61.1	60.4	36.0	28.0	57.8

the seedlings were still frozen, and then, subsequent to six-day thawing, on each date of planting for the root egress test. Carbohydrates were analyzed as described by Hansen and Møller (1975) and Iivonen et al. (2001).

2.5 Weather Conditions

Weather conditions varied considerably between study years (Table 3). In 1999 and 2001, May was colder; and in 1999 June and July as well as in 2001, 2002 and 2003 July was warmer than the long-term average. July 1998 and both spring and autumn 1999 were dry, and precipitation was lower than the 30-year average. According to the temperature sums, the 1998 growing season was colder and those of 1999, 2001 and 2002 were warmer than the long-term average.

2.6 Statistical Analysis

GRO98, GRO99, GRO00/A, GRO00/B and DOR01 were established according to a randomized block design and GRODOR00 as a randomized split-plot design, where planting date was the main effect (split) and growing state was a subplot. Due to mortality, plots contained different numbers of plants in consecutive measurements. In most cases, seedlings for a planting date were taken from one or two trays. In GRODOR00 and DOR01, dormant seedlings for each planting date were from the same cardboard box. Thus, within and between plots, seedlings planted on each date were correlated. Measurements in different years were also correlated. For these reasons data were analyzed by linear mixed models of SPSS 11.5.1 for Windows. For data in each year and variable (height and height growth) the model used was

$$y_{kijl} = \mu + w_j + g_i + wg_{ji} + \gamma_{kij} + \varepsilon_{kijl} \tag{1}$$

where μ is the general mean, w_j is the fixed effect of planting date j, g_i and wg_{ji} (only in GRODOR00) are the fixed effects of growing phase i and interaction of planting date w_j and growing phase g_i, γ_{kij} is the random plot effect for the plot k where growing phase i is planted during week j, ε_{ijkl} is the random effect of plant l.

In GRODOR00 and DOR01, the effect of planting week on probability of damage (binary variable) during autumn frosts and first winter was analyzed by the logit model

$$\log\left[\frac{\pi}{1-\pi}\right] = \alpha + \beta_j w + \beta_i g \tag{2}$$

In the analysis, planting week w_j was used as a continuous variable and growing phase g_i as a categorical variable (growing seedlings as the baseline). $[\pi/(1-\pi)]$ is the odds of damage. The model was fitted by using the binary logistic procedure of SPSS 11.5.1 for Windows.

Between-planting-date differences in root egress and concentration of carbohydrates in needles were analyzed by one-way ANOVA and Dunnett test after logarithmic transformation of the dry mass of new roots and the concentration of total sugars in needles (untransformed values are presented in the figures). In the Dunnett test the first planting date (22 May, length of the storage period 26 weeks) in May was used as the control.

Mortality and reasons for the weakening vitality of seedlings were analyzed by non-parametric Kruskall-Wallis test. The correlation between total sugar concentration in needles and root egress was tested by Pearsson's bivariate test.

3 Results

3.1 Survival and Damage

Survival of seedlings at the end of the fourth season varied in the different GRO experiments, but no significant differences were found between planting dates (Table 4). GRO98 was established in a nursery field, and for all planting dates survival was high (Table 4). In GRO99 mortality and damage were higher than in GRO98. The former was established on a disc-trenched site where the invasion of field vegetation to the prepared soil was strong in later years and the vigor of seedlings decreased independently of planting date. In GRO99, spring frosts in the nursery before planting damaged some of the terminal buds. Thus, after planting, these seedlings changed their leader shoot as they grew in height from lateral buds (Table 5). This probably also reduced the height growth in later years and made comparisons of height growth between planting dates unreliable since on the first planting dates there were more changed leader shoots or multiple shoots in seedlings whose buds were not broken before planting, and damaged buds were difficult to recognize (Table 5).

GRO00/A was established on a disc-trenched site and GRO00/B on a ditched and mounded site in the same clear-cutting area with the same seedling material and planted on the same date. Comparison of these experiments showed that, independently of planting date, mounding was more beneficial than disc trenching. Survival of seedlings planted on the mounded site was better than that of seedlings planted on the disc-trenched site (Table 4). In GRO00/A, at the end of the planting season more dried shoot tips were observed in spring plantings than in late-summer plantings (Table 5). In GRO00/A, the real reasons for damage and mortality were unclear, since 30% of the seedlings were not found (including dead seedlings) at the end of the fourth season. The most probable reasons, however, were the high water table during the rainy planting summer (for weather conditions, see Table 3) since at the end of the planting season, wet soil had already weakened some of the seedlings (Table 5). In later years, the rest of the seedlings suffered from the rapid invasion of field vegetation. Some of

Table 4. Survival of seedlings planted in spring and early summer four years after planting. All healthy and lightly damaged seedlings were scored as having survived. Statistical significance in average block survivals between planting weeks was analyzed by nonparametric Kruskal-Wallis test.

Experiment		May			June				July		
	20	21	22	23	24	25	26	27	28	29	p-value
GRO98		96	98	98	100	99	100	98	97		0.060
GRO99	52	52	58	51	51	73	39	52	52		0.505
GRO00/A		55		74		50		59		63	0.313
GRO00/B		94		90		94		92		88	0.370

Table 5. Proportion of seedlings with dried shoot tips and damage caused by excess water at the end of the planting season, with several shoots at the end of the second season or damaged by the pine weevil at the end of the fourth season. Statistical significances between planting dates were analyzed by nonparametric Kruskal-Wallis test. Only experiments with damage on some planting date were included in the table.

Experiment	May			June				July			
	20	21	22	23	24	25	26	27	28	29	p-value
Dried tips											
GRO00/A		12		17		1		1		1	0.004
GRO00/B		6		2		2		3		3	0.904
Excess water											
GRO00/A		40		26		44		23		7	0.137
Several shoots											
GRO99	25	37	29	26	21	16	14	12	18		0.004
GRO00/A		13		17		5		4		3	0.019
GRO00/B		18		24		15		15		5	0.015
Pine weevil											
GRO99	0	2	2	8	2	0	3	18	3		0.464
GRO00/A		1		0		1		3		3	0.190
GRO00/B		0		2		4		2		3	0.199

the seedlings could not found, and it is probable that more dead seedlings than were observed (Table 5) in the disc-trenched area were killed by pine weevils since those seedlings were not treated with insecticides before planting. Previously, Heiskanen and Viiri (2005) reported heavy damage by pine weevils in their experiment established on the same clear-cutting area during the same years. No differences between planting dates in the proportion of pine weevil damage were observed (Table 5). On the mounded part of the site, on the other hand, only a few seedlings were damaged or dead. On mounds, drought damaged some of seedlings, but still the average survival was higher than on the disc-trenched area (Table 4).

In the first inventory in August 2000, when seedlings has been planted from 31 May to 28 June in the GRODOR00, 1% of the growing seedlings had brown needles from the previous year. After that, the proportion of seedlings with brown needles increased: needles were damaged in 33, 85, 40 and 21% of the seedlings planted on 12 July, 26 July, 9 August and 23 August, respectively. According to logit model estimation, the later in June and July the seedlings were planted the greater the probability of seedling damage during the first autumn and winter (observed as damaged seedlings in the second autumn) increased, especially when they were dormant at the time of planting (Fig. 1, Table 6).

Table 6. Parameter estimates of the logit models for the effects of planting week on damage and mortality of Norway spruce seedlings for experiments established in 2000 (GRODOR00) and 2001 (DOR01). α=logit at baseline (in the year 2000 defined by dormant seedlings), and β_W=change in logit of damage and mortality with one week delay in planting week, β_D=logit difference between dormant and growing seedlings.

Parameter	Estimate	S.E.	Wald test (p)	Odds ratio
Year 2000				
α	–18.121	1.337	<0.0001	<0.0001
β_W	0.621	0.046	<0.0001	1.862
β_D	–4.774	0.3413	<0.0001	0.008
Year 2001				
α	–7.753	1.526	<0.0001	0.0004
β_W	0.203	0.056	0.0003	1.226

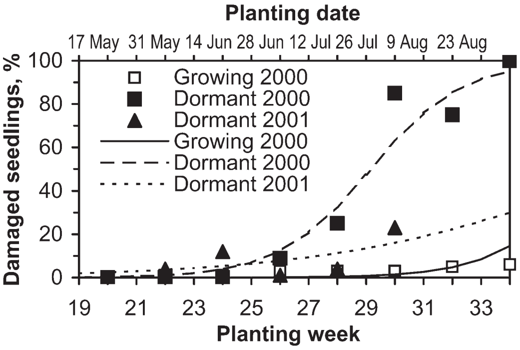

Fig. 1. Probability of damage (includes dead and severely damaged seedlings in the second autumn) of growing (2000) and dormant (2000, 2001) Norway spruce container seedlings caused by autumn frost and winter in different planting weeks (calendar week, in the upper x-axis in the corresponding planting date). Symbols indicate the observed mean damage in field experiments, and lines show the estimated probabilities of damage (these estimates are presented in Table 6). In 2000, damage of dormant seedlings was compared to damage of growing seedlings planted at the same time.

Parameter βw shows that if seedlings were planted a week later, the odds ratio for dormant seedlings increased to 1.9 (Table 6). If the seedlings were growing at the time of planting, the odds ratio decreased to 0.008 (βg). In DOR01, compared to dormant seedlings in GRODOR00, the probability of damage to dormant seedlings with plantings later in summer was lower on all planting dates (Fig. 1).

3.2 Height Growth

In GRO98, GRO99, GRO00/A and GRO00/B, seedlings planted later in summer were taller at the time of planting than were seedlings planted on the first date in May (Table 7, Fig. 2). On the other hand, the later seedlings were planted the less they grew during the first season after planting. Despite the better growth, seedlings planted in May were still shorter at the end of the first season than those from later plantings. The reason for this was that seedlings planted later in summer grew better in the nursery conditions (regular irrigation, fertilization and higher growing density) before planting than did seedlings grown for the corresponding time on the forest site. During the second season, seedlings planted in late June (GRO99) and in July (GRO98, GRO99, GRO00/B) grew less than did seedlings that had been planted earlier. For the final height at the end of the 2nd season in GRO98, GRO99, GRO00/A and at the end of the 3rd season in GRO98 and GRO99, seedlings planted in July were shorter than those that had been planted earlier. In later years, however, there were no differences in height growth or final height between planting dates (Table 7). When the GRO00/A and BRO00/B were compared, in the planting summer, seedlings planted on the disc-trenched site (GRO00/A) had better height growth; but in

Table 7. Mixed model analysis of variance, fixed effects of planting date on height (H) and height growth (G) at the time of planting (0) and at the end of each growing season from 1 to 4 years after planting.

Variable	GRO98		GRO99		GRO00/A		GRO00/B		DOR01	
	F	p	F	p	F	p	F	p	F	p
H0	91.7	<0.001	60.5	<0.001	71.1	<0.001	84.4	<0.001	47.5	<0.001
G1	29.8	<0.001	6.0	<0.001	2.6	0.059	52.8	<0.001	4.8	0.008
H1	25.7	<0.001	3.1	0.007	21.5	<0.001	38.9	<0.001	21.0	<0.001
G2	5.0	<0.001	6.5	<0.001	0.2	0.931	11.7	<0.001	33.8	<0.001
H2	4.4	0.001	2.4	0.028	27.3	<0.001	6.2	0.001	33.0	<0.001
G3	3.5	0.005	1.5	0.198	1.3	0.315	1.7	0.173	9.8	<0.001
H3	1.1	0.406	2.2	0.045	3.5	0.022	0.4	0.789	32.1	<0.001
G4	1.9	0.102	0.8	0.585	2.0	0.123	0.6	0.663		
H4	1.6	0.179	1.4	0.233	1.6	0.199	0.1	0.982		

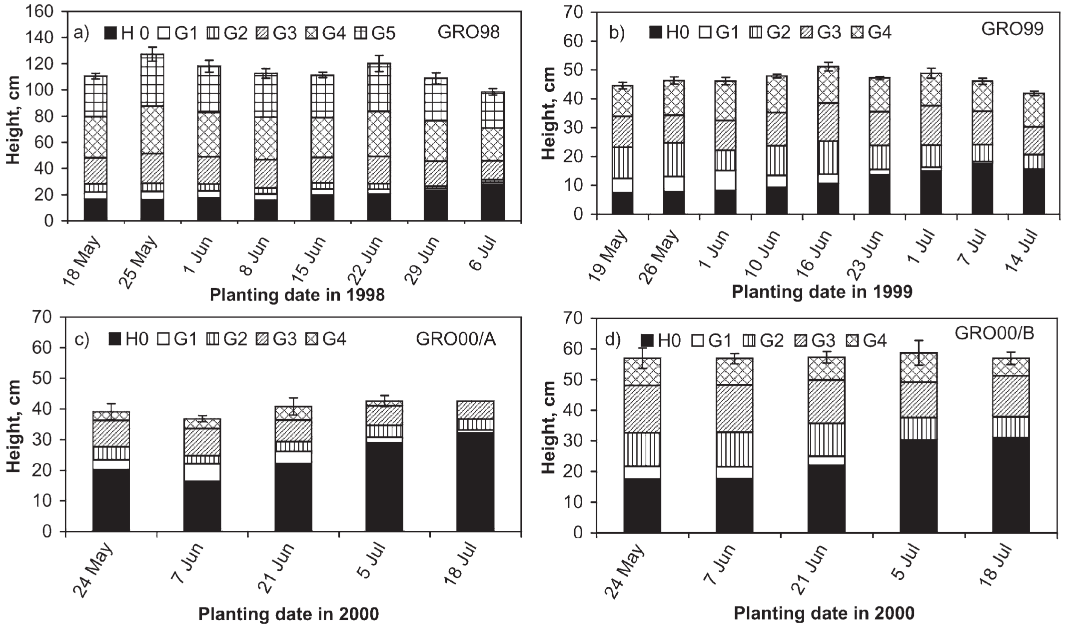

Fig. 2. Height and height growth of Norway spruce container seedlings in experiments established a) on the nursery field in Suonenjoki in 1998 (GRO98), b) on a disc-trenched forest site in Pieksanmaa in 1999 (GRO99), c) in Suonenjoki in 2000 (GRO00/A), and d) on a mounded forest site in Suonenjoki in 2000 (GRO00/B). In each experiment, on each planting date the seedlings planted were from the same seedling batch. Both experiments established in 2000 contained seedlings from the same batch. H0 = height at planting, G1–G5 = growth of the first to fifth year measured at the end of each growing season.

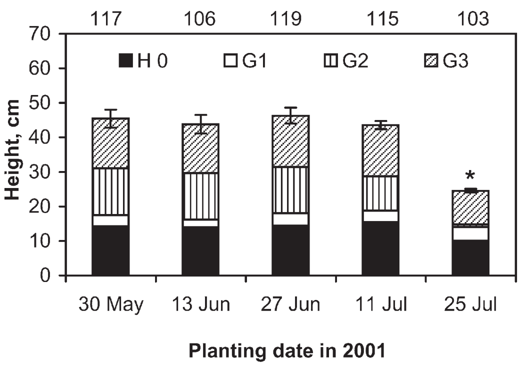

Fig. 3. Height and height growth of dormant Norway spruce container seedlings planted into the old nursery field in Suonenjoki in 2001 (DOR01). Seedlings were over-wintered in frozen storage. For explanations of symbols, see Fig. 2. The number of living seedlings in the last inventory is marked above each bar. *Statistically significant differences ($p < 0.05$) after 4 years compared to the first planting date in spring.

later years the height growth of seedlings planted on the mounded site was better than that on the disc-trenched site (Fig. 2 c and d).

In DOR01, the growth of dormant seedlings differed between planting dates, so that seedlings planted on 25 July grew less than those seedlings planted on 30 May (Table 7, Fig. 3). Height at the end of each season also differed between planting dates so that poorly growing seedlings planted on 25 July were shorter than seedlings from the first planting date in May.

In GRODOR00, dormant and growing seedlings were the same size at the first planting date on 17 May; they also grew similarly, and their final height at the end of each season was the same (Fig. 4, Table 8). Dormant seedlings were about the same size at each planting date; but for seedlings planted in the growing phase, the later they were planted the taller they were (Fig. 4). Correspondingly, the earlier they were planted the

Table 8. Mixed model analysis of variance, fixed effects of growing phase *g* (growing or dormant) and planting date *w* (biweekly from 17 May to 23August) on height (H) and height growth (G) at planting and 1 and 2 years after planting in the GRODOR00 experiment.

Variable	Source	GRODOR00 F	p
H0	g	91.2	<0.001
	w	4909	<0.001
	$w \times g$	227.0	<0.001
G1	g	21.8	<0.001
	w	66.6	<0.001
	$w \times g$	4.2	<0.001
H1	g	6.6	<0.001
	w	613.0	<0.001
	$w \times g$	53.9	<0.001
G2	g	3.1	0.011
	w	0.8	0.378
	$w \times g$	0.8	0.591
H2	g	60.2	<0.001
	w	608.6	<0.001
	$w \times g$	85.4	<0.001

better both dormant and growing seedlings grew during the first season after planting (Table 8). In later years, the final height of seedlings planted before mid-June did not differ with regard either to planting dates or to growing phases. For both dormant and growing seedlings, those planted after mid-June grew less, and the later seedlings were planted the shorter was their final height at the end of each season. This trend was much stronger in dormant seedlings than in growing seedlings.

3.3 Root Egress and Carbohydrates

In GRO99, root egress did not differ between planting dates in May and early June, but it increased after mid-June (Fig. 5a). In DOR01, root egress of growing seedlings was low in May and June but increased rapidly in July (Fig. 5a). Increasing root growth after mid-summer correlated to some extent with height growth during the root egress test: when height growth slowed down or ceased, root growth increased (Fig. 5b). In seedlings that were dormant at planting, the dry

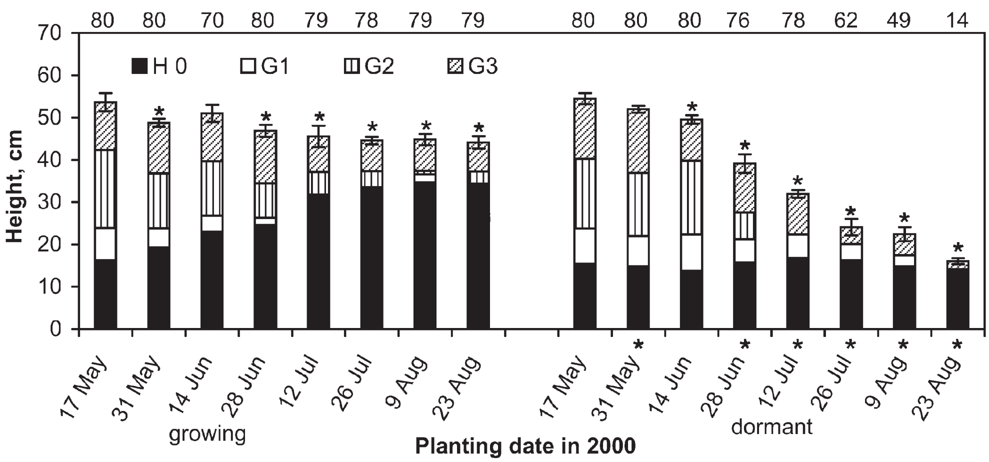

Fig. 4. Height and height growth of growing (left bars) and dormant (right bars) Norway spruce container seedlings planted on the old nursery field at Suonenjoki in 2000 (GRODOR00). Growing seedlings were winter-stored outdoors in trays and dormant seedlings in cardboard boxes in frozen storage. For explanations of symbols, see Fig. 2. The number of living seedlings in the last inventory is marked above each bar. *Statistically significant differences ($p<0.05$) after 4 years compared to the first planting date in spring (above the bars) or growing seedlings in each week (below the x-axis).

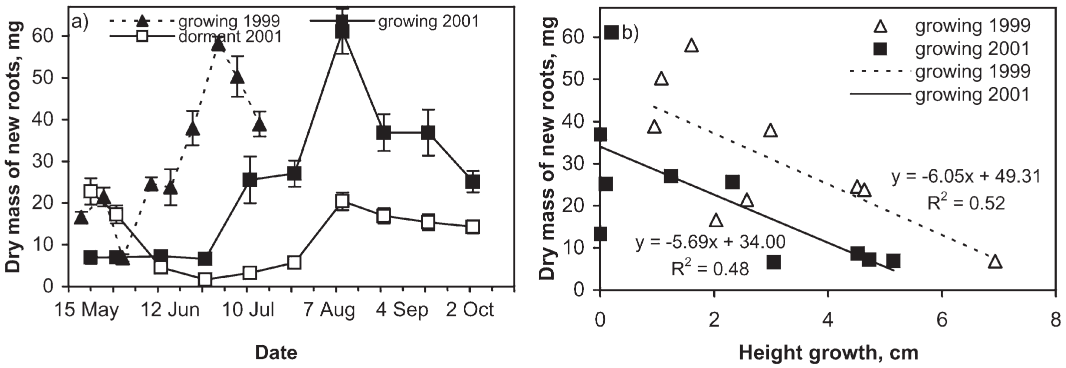

Fig. 5. a) Root egress (dry mass of new roots grown out from the peat plug into sand during the three-week test period in a greenhouse) of growing and dormant Norway spruce container seedlings planted on different dates in 1999 (GRO99) and 2001 (DOR01). b) Correlation of height growth and root growth (during the root egress test) of actively growing seedlings.

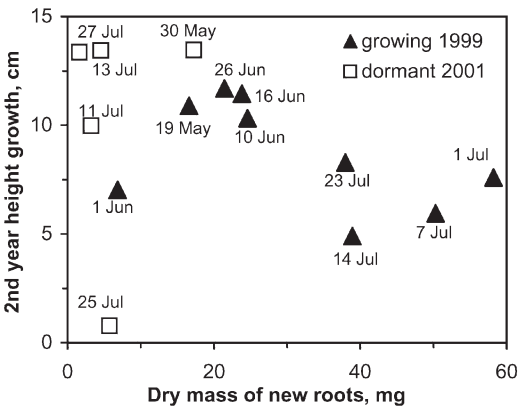

Fig. 6. Relationship between root egress (mg) and second-year height growth (cm) in the field for growing and dormant Norway spruce container seedlings. Numbers above or below symbols indicate the planting date. Each symbol is the mean of all values for each planting date and experiment.

mass of new roots grown out from the peat plug was low throughout the whole season. In May, the root egress of dormant seedlings was, however, greater than that of seedlings stored outdoors. The effects of root egress on field performance could be compared in the growing seedlings in GRO99 and in the dormant seedlings in DOR01.

In dormant seedlings, root egress did not explain the second-year growth of the seedlings after planting (Fig. 6). In growing seedlings, however, the correlation was negative, although not linear: the smaller the root egress was the better was the height growth of the seedlings during the second season in the field (Fig. 6).

The thawing of seedlings did not affect the concentration of total sugars or the concentration of soluble sugars; but during the 6-day thawing period, the concentration of starch in needles increased ($p = 0.003$) (Fig. 7a). Lengthening of the time in frozen storage decreased the concentration of total sugars in needles ($p < 0.001$), but differences between the shortest period (29 weeks) and storage durations of 32 and 34 weeks were small. With lengthening storage period the starch concentrations of needles increased ($p < 0.001$). On the other hand, compared to the first planting date, when storage lasted over 34 weeks, lengthening of storage duration decreased the concentration of soluble sugars ($p = 0.001$). The reduced concentrations of sugars in needles also reduced the root egress of seedlings (Fig. 7b). The correlation between variables, however, was not significant (Pearson's correlation coefficient 0.624, $p = 0.073$).

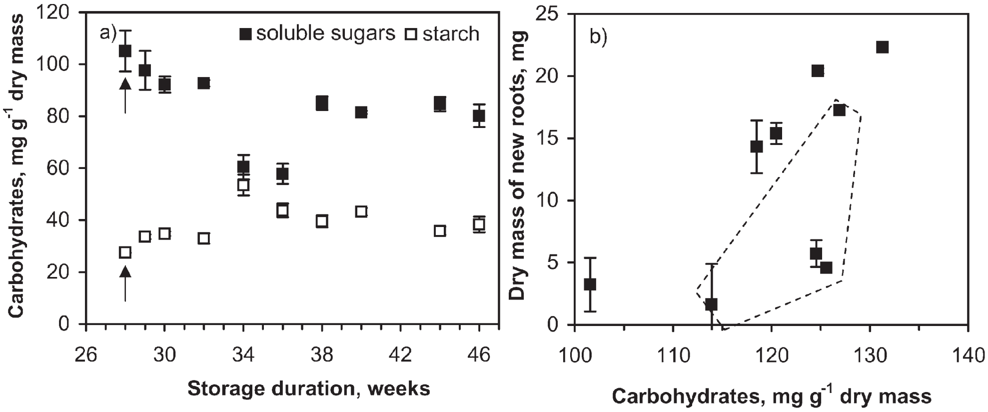

Fig. 7. a) Total sugar and starch concentrations in needles of dormant Norway spruce container seedlings with different storage durations. Arrows indicate concentrations after frozen storage but before thawing. b) Correlation of total sugar concentration and root egress (dry mass of new roots grown out from the peat plug into sand) of seedlings. Symbols surrounded by a dashed line indicate cases where damage was caused by aphids or gray mould during the test.

4 Discussion

Both growth and survival results showed that the planting period for Norway spruce container seedlings can be extended from May to the middle of June. When seedlings were planted after mid-June, growth of the actively growing seedlings in some experiments and survival of dormant planted seedlings decreased in later years.

Our results support those of previous studies (Söderström 1974, Raulo and Rikala 1981, Örlander et al. 1998) showing that the seedlings' risk of dying is smaller and height growth better on the mounded site than on the disc-trenched site. As was the case in our study, in which some seedlings on the mounded site were damaged by drought, the risk of drought damage during dry summers can increase if seedlings are planted on mounds in the summer months. This damage, however, was not as severe as that caused by the pine weevil and the rapid invasion of field vegetation on the disc-trenched site.

These results indicate the importance of temperature conditions for field performance of dormant planted seedlings. The summer of 2001 was warmer than the summer of 2000, and in 2000 the first autumn frost came already on 7 September, while the first night frost in 2001 was not until the end of September (Table 3). The consequence was that, of the seedlings planted in mid-June in 2000, about 10% were damaged, while in 2001 only a few seedlings were damaged. However, this kind of results related to weather conditions (see also Ericsson et al. 1984) is difficult to generalize across years. Risk analysis based on long-term climatic data gives more general information about potential frost risks for different planting dates. Based on 50-year climate data from Central Finland, Hänninen et al. (2002) showed that seedlings planted around 10 June will be damaged by autumn frosts every tenth year, those planted on 20 June will suffer from frost every fifth year and those planted on 30 June will suffer autumn frost damage as much as every second year.

According to our results, field performance of dormant and growing Norway spruce seedlings planted before mid-June did not differ. In a small-scale field test, Helenius et al. (2005) showed that, if there is no drought, growing Norway spruce seedlings have more rapid root egress after planting than dormant seedlings do. However, growing seedlings are more sensitive to drought; thus, if a very long (2–3 weeks) period of drought occurs after planting, roots of dormant seedlings grow better (Helenius et al. 2005).

After mid-July, root egress increased in the growing seedlings but not as much as in the dormant seedlings (Fig. 5a). In the study of Kaakinen et al. (2004), when growth of the similar growing seedlings was monitored, accumulation of root biomass was also slow until mid-July, when height growth ceased. In our study, root egress of seedlings planted on different dates correlated to some extent with the amount of height growth in the greenhouse (Fig. 5b). In the root egress test, bud damage (Table 2) caused by night frost before planting probably affected both the root and height growth of growing seedlings. Increased root growth after mid-June did not, however, explain the field growth of seedlings in the second season after planting (Fig. 6). According to Burdett (1987), high potential for root growth plays a major role in determining the ability of newly planted seedlings to avoid water stress, which in turn determines the early survival and growth of seedlings (Burdett 1990). However, even though the roots grow well, if the needles are damaged (aphids, gray mould) or seedlings have suffered stress before planting, the performance potential of the seedlings will be lowered, as was the case in this study.

After mid-June, the seedlings were probably too tall in relation to container size at the time of planting; i.e. they grew too densely in the nursery, and in later years their growth was reduced (Figs. 2 and 4). This corresponds to the results of Hultén (1991) for Norway spruce and those of Paterson (1997) for black spruce (*Picea mariana*) container seedlings. With the dense spacing of seedlings in the nursery, needles in the lower part of the stem are sensitive to fungus infections and do not receive enough light. Then after planting these needles suffer drought and radiation stress; and if they have not died already in the nursery, they die after planting. This was observed in GRODOR00, where the later the seedlings were planted the more seedlings with brown previous-year needles appeared during the first autumn. In any case, in later years growth after planting is probably reduced due to the decreased surface area of photosynthesizing needles. In the root egress test, these taller seedlings that had been planted later had better root growth in greenhouse conditions (Fig. 5a), which could not compensate for the negative effects of growing density and thus did not improve the second-year growth in the field (Fig. 6) as has been expected. Therefore, despite rapid rooting, the field growth of the seedlings decreased.

As found in experiments established in 2000, when new shoots are succulent and too long, there is a risk of mechanical damage to freshly-lifted seedlings. Mechanical damage was, however, observed only in July. Previously, Helenius (2002) showed that new shoots of Norway spruce seedlings are brittle, which in June and early July may cause them to break. If shoots break, growth after planting may be reduced and seedlings may become bushy or curvy. However, the mechanical stress, if not too heavy, has not been shown to affect the survival and growth of growing conifer container seedlings negatively (Simpson et al. 1994, Stjernberg 1997, Helenius et al. 2002).

In our experiment, for all planting dates the average concentration of soluble sugars was 81.3 mg g^{-1} dry mass, which was higher than the concentrations observed by Fløistad and Kohmann (2001) but lower than those reported by Kaakinen et al. (2004) and Helenius et al. (2005) for Norway spruce container seedlings. The six-day thawing of seedlings did not affect the concentrations of carbohydrates. Fløistad and Kohmann (2001) showed that slow thawing (1 month, +5 °C) of Norway spruce seedlings decreased the sucrose and raffinose concentrations in the needles, but rapid thawing with immersion in water did not affect these concentrations. If seedlings were planted after winter storage, the duration of storage did not affect either the total sugar (soluble sugar + starch) or the starch concentration (Fig. 7a); but the concentration of soluble sugars was reduced. In Scots pine seedlings, Puttonen (1986) showed that lengthening of storage time decreased the total sugar concentrations in needles and that this depletion weakened the post-planting success of seedlings. The increase in starch concentrations in July was probably caused by photosynthesis during a 2-day period in the shaded shelter before planting. In July, light levels and air temperatures were higher during the 2-day part of the thawing period than in June and August. According to Fischer and Höll (1991), photosynthetic activity in early spring can increase starch levels in Scots pine needles when active sinks (growth) are lacking.

The depletion of total sugars in needles tended to reduce root egress after planting (Fig. 7b), although the correlation was not significant. On some planting dates, gray mould and aphids were found on the needles. This probably reduced root egress but did not affect carbohydrates, which were assessed only in needles. Philipson (1988) showed that although current photosynthates are the main source of root production in Sitka spruce (*Picea sitchensis* (Bong.) Carr.) seedlings, starch reserves in roots may be the energy source for growth of new roots; thus root growth is not dependent only on current photosynthates.

In conclusion, the planting period can be extended from spring to early June with both frozen-stored dormant and growing seedlings. Growing seedlings targeted for spring planting can be planted even later in summer, but the risk of mechanical damage and reduced growth after planting increases. After the middle of June, the risk of autumn frost damage in dormant planted seedlings increases. Duration of storage, which was longer than in the conventional spring planting, did not cause depletion of carbohydrates or reduced root growth. The effect of rapid root egress in July on field performance of seedlings was minor. Risks related to different planting dates in practical scale plantings and proper seedling material targeted for plantings after mid-June should be studied further.

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